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Description of a new Air-pump, with an investigation of the limit of Exhausting Power in various constructions of that Instrument. *By* T. R. Robinson, D. D. M. R. I. A. *Professor of Astronomy at Armagh.*

Read October, 24, 1825.

THE improvement of the Air-pump has long been an object of attention to the votaries of Physical science; and particulary of late years, as the recent discoveries in chemistry have made its use indispensable to every experimenter who wishes to attain that accuracy in operating on gases, which is now essential. A great number of ingenious contrivances have accordingly been devised to augment its power, but I am not aware that the actual value of them has ever been theoretically determined. The common treatises of pneumatics contain theorems assigning a geometrical progression to the densities of the air after successive strokes, but these are false except in a case which can never be found in practice, and are also useless, as we are only concerned with the ultimate exhaustion. Perhaps therefore, the following results may not be unacceptable, though obtained by the simplest possible calculation.

The Air-pump which is in common use, was invented by Hooke: the elasticity of the air in its receiver, lifts a leather valve, and opens a communication between the receiver and the pump barrel, partially exhausted by the ascent of its piston. This force is opposed by the elasticity of the air previously contained in the barrel, and by that of the valve itself; when they balance it the valve cannot be raised, and the exhaustion is at its limit, which limit is therefore given by an equation between these three forces.

Let S be the space below the piston when raised to its greatest height, s that remaining when it is depressed as much as possible, A the altitude of the barometric column, v a column of mercury the pressure of which would open the valve, and x that which measures the density of the air in the receiver: then as in this construction the piston valve (which is similar to the receiver valve) is opened against the pressure of the atmosphere, the space s at the termination of a stroke remains full of air whose density is $A+v$. Let the piston be drawn up, and this air will expand till its density becomes,

$$(A+v)\frac{s}{S}$$

therefore

$$x=(A+v)\frac{s}{S}+v.$$

The quantity v is found by experiment to be about 0. 2. and therefore if the workmanship were so perfect as to leave no space below the piston when depressed, this must be the limit of exhaustion, corresponding to a rarefaction of 150 times. In fact, x never is less than 0. 3, or the best of these machines do not exhaust 100 times. Smeaton made the first great improvement on this construction, by closing the top of the barrel with a collar of leather, through which the piston rod works air-tight, so that in its descent, a partial vacuum is left above the piston, and on its return, the air which had entered this through the piston valve, is discharged into the atmosphere through a valve on the top of the pump. He also altered the construction of the receiver valve, but I believe the change was no improvement. Let S' be the space *above* the piston when depressed, s' when elevated, then when the limit is attained, the air below the piston must be unable to open the piston valve, and therefore its density is by the last equation

$$v+\frac{s'}{S'}\times(A+v).$$

When the piston is raised to the top of the barrel this becomes

$$\frac{s}{S}\times v+\frac{s\,s'}{SS'}\times(A+v);$$

and as this elasticity, together with that of the receiver valve prevent the air in the receiver from expanding, we have

$$x=v'+\frac{s}{S}v+\frac{s\,s'}{SS'}\times(A+v).$$

Smeaton's pump is therefore little better than Hooke's, as x cannot be less than 0. 2, though as the remaining part of the expression is small it cannot much exceed it. If however the receiver valve were opened mechanically as in the pump of Haas, it becomes far superior, for v' disappears in the expression, and $\frac{s}{S}$ is always an inconsiderable fraction.

In Prince's machine, the piston in its ascent passes an aperture communicating with the receiver, and the air which thus enters is expelled in its descent through a discharging valve; if this be leather, it is evident that

$$x=\frac{s}{S}\times(A+v).$$

Mr. Kiernan has described an improvement of this in the 13th volume of our Transactions, which consists in making the discharging valve metallic, and opening it by a simple but effective mechanism; thus v disappears from the second factor, which however is of little consequence, but s may be made scarcely perceptible;

and the instrument was found to perform as well as any that have met my observation.

But Mr. Prince went further; he connected the discharging valve with a second pump of similar construction; and the elasticity of the air remaining in this, plus the elasticity of the discharging valve, must equal the elasticity of the air in the receiver, augmented by being condensed from the bulk S into s; therefore

$$\frac{S\,x}{s} = v + \frac{s'}{S'} \times (A + v)$$

$$x = \frac{s}{S} \times v + \frac{s\,s'}{SS'} \times (A + v)$$

an expression identical with the performance of Haas's pump. It is however laborious to work, and exhausts only at the end of the stroke.

That form is perfect in which the receiver communicates *freely* with the space S, and when the air which expands into this is condensed into s, this latter communicates *freely* with S'. In such an instrument

$$x = \frac{s\,s'}{SS'} \times (A + v)$$

Such is described by Mr. Little in vol. VI. of our Transactions, but it requires s and s' to be of considerable magnitude. Mr. Cuthbertson's machine is similar in principle, but in it the spaces above and below the piston are connected for an instant while the receiver valve is open; to say nothing of the complexity of its construction, which is difficult either to execute or keep in order.

The Air-pump which I have the honour of proposing to the Academy, seems to possess peculiar advantages, while its parts can be made by ordinary workmen, and it can be afforded at a much less price than most of those which can pretend to equal it in power. A section of it is exhibited in plate 1.

B is the barrel provided with a solid piston *P* whose rod slides air tight in the collar of leathers *M* : *C* and *D* are valves opening into the atmosphere. The barrel communicates at *E* with a smaller barrel *G*, containing the receiver-valve, or rather the apparatus that performs its office. This is soldered to the body of the pump, and its orifice is in the upper flanch of it, so that the top plate when screwed down covers both ; it has a piston *H*, rather less than half its length, accurately fitted, which is perforated and provided with a valve at *I* opening upwards. The rod of this slides also in a collar of leathers, and is supplied with a spiral spring of sufficient strength to keep it always at the top of its barrel. *K* is the receiver pipe communicating with the barrel *G* by a small aperture *O*. In the operation of this instrument, two distinct modifications are presented ; at first it is equivalent to the action of a *double barrelled* pump of the common construction, exhausting both in the up and down strokes: but when the exhaustion becomes the quantity which I denote by the symbol v, its action changes, and it becomes equivalent, or indeed superior to, a single barrel of Cuthbertson's construction. Suppose the piston at the top of *B*, and let it be depressed, the air below it is driven through *C*, while that contained in the receiver comes through *K O*, and raising the valve *I*, passes at *E* into the space above *P*. On the return of the piston the valve *I* closes, and nearly all the air is discharged into the atmosphere through *D*; till at the end of the stroke, when *P* has risen above the aperture *F* (which communicates with the passage *E* by a perforation drilled in the solid brass of the barrel.) *I* opens again, and the air of the receiver expands through *F* into the space below *P*. This is discharged at *C′* in the next stroke, and so on, as long as the elasticity of the air is able to open *I*. But in this we have supposed the piston *H* to remain fixed, which is not the case; for when *P* is at the bottom of its barrel, *H* is depressed *below* *O* by a cleat fixed to the rack which moves *P*, and thus a *free* communication is established between the receiver and the passage *E*. As before, suppose *P* at the top of *B*; *H* is also at the top of *G*; on depressing *P*, while the space below it discharges its air at *C*, that above it is left exhausted, for the valve *I* cannot be opened by the rarified air. At last the cleat already mentioned forces down *L*, and the air in the receiver expands into the barrel: on raising the piston, *H* rises to its place and shuts off the communication; and the air in the upper part continues to be condensed by the ascent of the piston till it passes *F*, when a *free* passage is opened between the two portions of the barrel, and the air passes from the upper to the lower, from which it is discharged at the descent of *P*.

The valves *C*, *D*, and *I* are leather; and the piston *H* is in my opinion preferable to any valve both for the ease with which it can be made and the security of its action: if any part may seem objectionable, it is the narrow passage *E F*, but the trials which I made of Mr. Kiernan's pump, in which the piston passed a small aperture, shew that no inconvenience can result from it.

If a still higher exhaustion be required, screwing an exhausted flask on *C* we have

$$x = v \times \frac{s\,s'}{S S'} + (A + v) \times \frac{s^2 s'^2}{S^2 S'^2}$$

in which the second term is altogether insensible, and this mode of proceeding secures the valve *C* from leakage, thus enabling the machine to exert its full power.

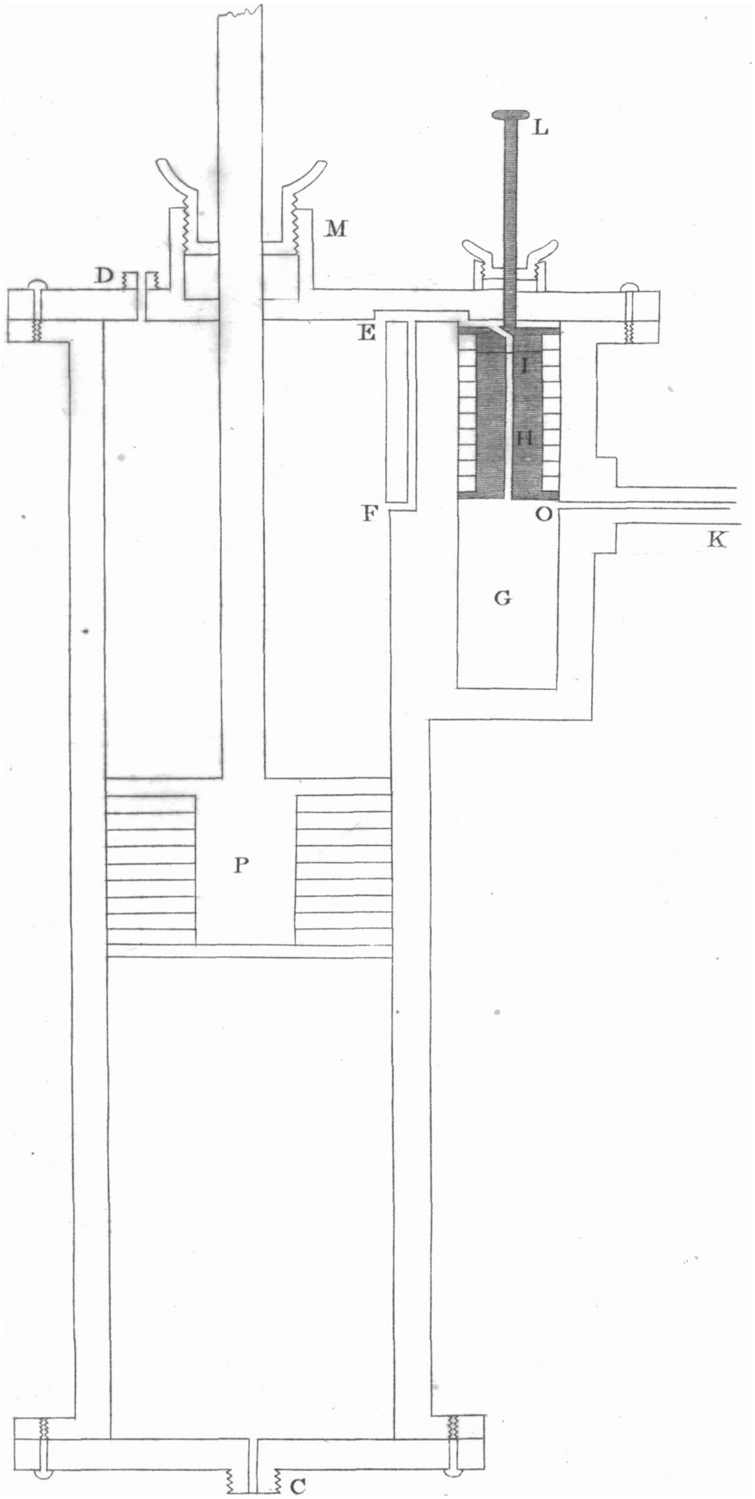
To exhibit the comparative values of the results obtained above, suppose $v = 0.\,2$, $A = 28.\,8$, and $\frac{s}{S} = \frac{1}{300}$ which is easily attainable by the commonest workman, we have

1. Hooke's pump gives x = 0. 3, Exhaustion = 96 times.
2. Smeaton's, - - - - 0. 201, - - - - 146.
3. Haas's, - - - - - 0. 001, - - - - 28800.
4. Kiernan's, - - - - 0. 096, - - - - 300.
5. Prince's, - - - - 0. 001, - - - - 28800.
6. That described above, 0. 00032, - - - 90000.
7. Same as in last paragraph, 0. 000002, - - - 14400000.

These high numbers are of course only arithmetical expressions of the theoretical value of the instruments; the second and fourth are below the performance actually obtained, while the fifth and all yet constructed of the sixth must fall short of what I assign to them; it remains to find whether mine will approach nearer to the limit.

T. R. ROBINSON.

October, 26, 1822.



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